

2008 October 21

To: Collaboration  
From: M. Syphers  
Subject: Possible Scheme to Ameliorate Space Charge and Momentum Spread Issues

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The large momentum spread ( $\sim 0.8\%$ , rms) and large space charge tune shift/spread ( $\sim 0.1$ ) of the final beam bunch in the Debuncher for our present parameter set are both challenging values, in particular when it comes to slow resonant extraction from the ring. The large momentum spread not only makes the beam larger within the aperture of the Debuncher (in regions of dispersion) and makes stronger demands on the necessary RF voltage for containing the bunch, but it also makes stricter demands on the control of chromaticity (tune *vs.* momentum) in the ring while particles are purposefully placed on resonance with the betatron tune. Similarly, the large tune spread created by space charge could make the control of the resonance and the particle step size across the electrostatic septum more difficult as well. Measures to reduce both of these parameters would certainly make the extraction process more robust and more easily controlled.

Work has been performed to study the possible development of bunches in the Recycler ring that could then be delivered to the g-2 experiment, all during a 15 Hz Booster cycle. In this scenario,<sup>1</sup> within one 67 ms cycle a Booster batch is loaded into the Recycler and manipulated using a broadband RF system, a 2.5 MHz RF system, and a 5.0 MHz RF system. The systems used would be the existing systems of the Recycler and Main Injector (moved to the Recycler ring), with possible slight upgrades to them. In the scheme, four bunches with rms bunch lengths of about 30 ns are generated within 30 ms, and then transferred one at a time toward the g-2 experiment.

One should consider using the scheme for g-2 to generate bunches for use in *Mu2e* by transferring directly to the Accumulator and Debuncher rings every 15 Hz cycle.<sup>2</sup> For *Mu2e*, for example, these four bunches could be single-turn extracted and transferred to the Accumulator ring. From there, they could be kicked one-at-a-time into the Debuncher ring from which they would be slowly extracted.

By appropriately staggering the beam transfers, this procedure can be used in principle to generate four slow spills from the Debuncher every Booster cycle. Let's examine the implications of this particular scenario. Figure 1 shows the time line of the present *Mu2e* scheme, while Figure 2 schematically shows the possible new scheme. First of all, we note that if 6 pulses are used during the Main Injector cycle, with  $4 \times 10^{12}$  (4 Tp) per pulse, both schemes will provide the

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<sup>1</sup>C. Bhat, J. MacLachlan, "RF Requirements for Bunching in the Recycler for Injection into the g-2 Ring," Beams-doc-3192 (28 Aug 2008).

<sup>2</sup>M. Popovic, private communication.

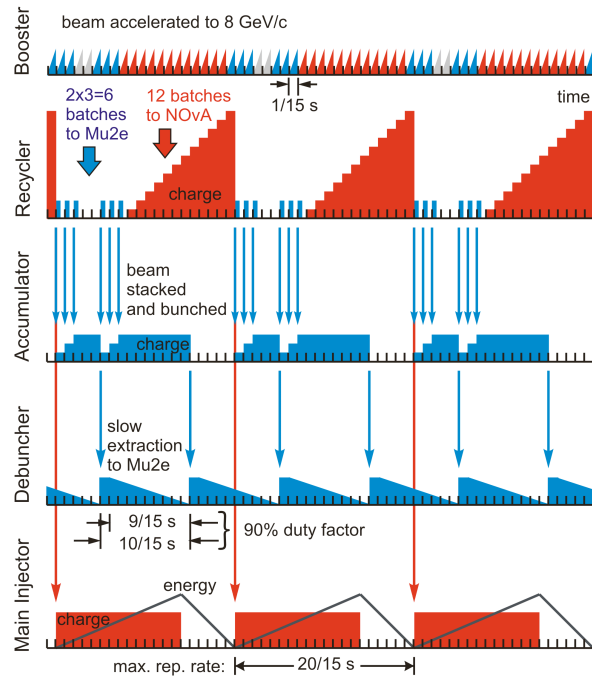


Figure 1: Timing diagram, from the present *Mu2e* proposal.

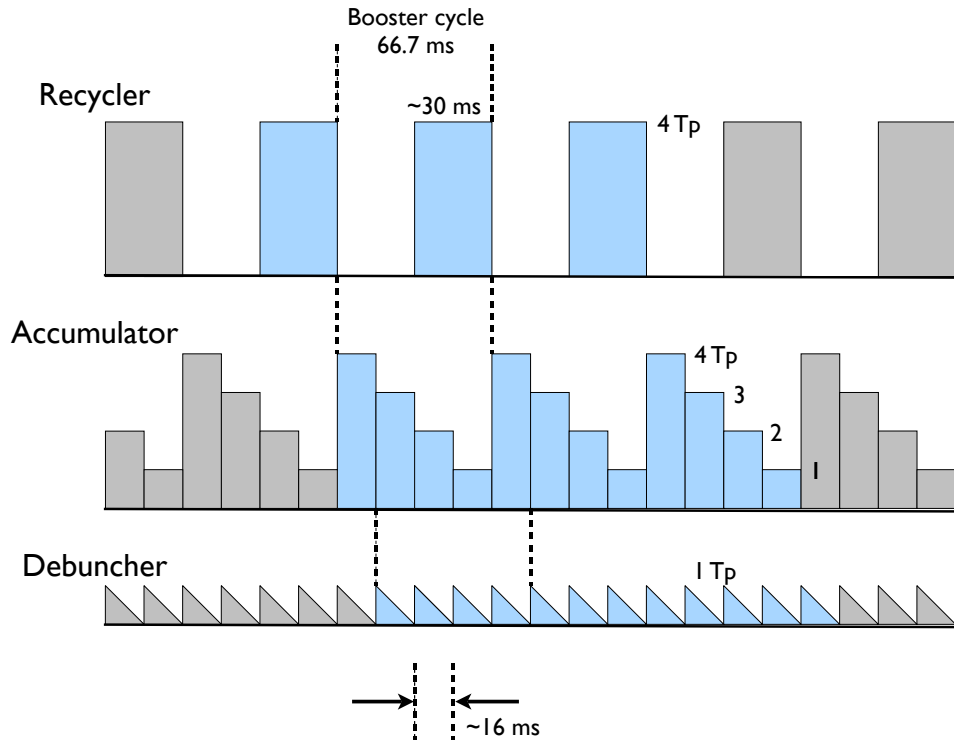


Figure 2: Timing diagram for the scenario being presented.

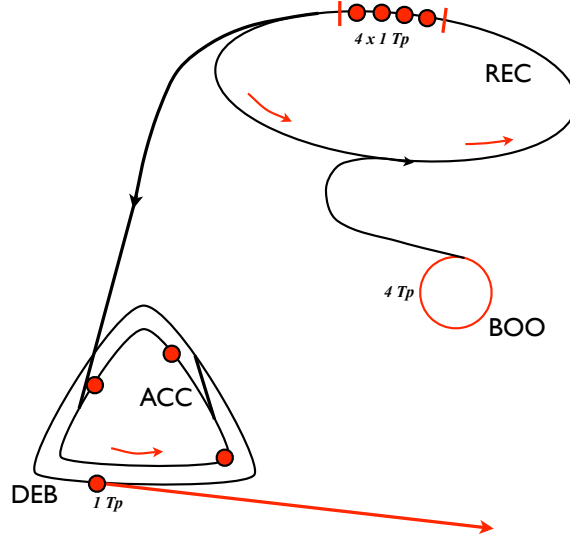


Figure 3: Schematic of the Debuncher fill scenario being presented.

same *average* particles per second to the experiment, namely 18 Tp/s. The most significant difference for the experiment will be that the new scheme would send bursts of particles from the Debuncher with an increased intensity. Rather than 12 Tp spilled over 600 ms, there would be 1 Tp spilled over about 16 ms. That is, rather than  $3.4 \times 10^7$  per burst there would be  $\sim 10 \times 10^7$  per burst. The macro-duty factor would be on the order of 30% (6 Booster cycles out of 20 during a Main Injector ramp).

However, with this increased instantaneous rate to the experiment comes a reduction of beam current in the rings and added robustness to the extraction scheme. The total beam intensity in the Accumulator ring is cut by a factor of three (12 Tp to 4 Tp), and in the Debuncher ring by a factor of 12 (from 12 Tp to 1 Tp). Thus, the space charge tune shift in the Debuncher (and Accumulator for that matter), barring no other mitigation such as phase space painting, is reduced by the same factor to a congenial  $\Delta\nu \sim 0.008$ . Furthermore, the momentum spread generated in the Recycler and maintained in the Accumulator and Debuncher would be a factor of four less, or 0.2%<sup>3</sup> rather than 0.8%. This will reduce the voltage requirements of the  $h = 4$  systems required now in both of the smaller rings, and removes the necessity of any  $h = 1$  systems.

Other changes implied by the scenario:

- Since the Recycler will not be used as a simple transport system, the pulsed extraction magnet will need to be replaced by an appropriate kicker magnet system.
- The extraction/injection kickers for the Accumulator/Debuncher transfers will need to be able to pulse 4 times during a 67 ms period (60 Hz).
- The slow spill feedback system will have to handle the shorter spill time of 16 ms ( $\sim 10,000$  turns). This will need to be demonstrated (as would 600 ms).

<sup>3</sup>MacLachlan, Bhat, *op. cit.*.

Table 1 compares various parameters of the two scenarios. It should be noted that with this scenario, the experiment would be able to utilize any spare 15 Hz Booster cycle. Thus, if it is deemed that all 8 spare Booster cycles during a Main Injector 1.333 s super-cycle can be used, the experiment gets beam 4/3 times faster with no changes to the operation – simply more cycles. If NO $\nu$ A is not running and the experiment can take all Booster cycles, then it receives a full 60 Tp/s average rate with a duty factor of 90% or better. This alleviates having to create special time lines and additional stacking in the Accumulator to take advantage of empty Booster cycles.

Should g-2 come to be funded and is brought on line first, then the same kicker and extraction system can be used for both experiments as well as the same Recycler RF systems for bunch formation, giving *Mu2e* a head start in operational experience with the bunch formation process.

Table 1: Parameter Comparison with *Mu2e* Proposal.

	<i>Mu2e</i> Proposal	suggested scenario	
$p$ momentum on target	8.89	8.89	GeV/c
Booster Rep. Rate	15	15	Hz
MI cycle	20	20	1/(15 Hz)
Pulses per MI cycle	6	6	
$p$ per Booster cycle	4	4	Tp (10 <sup>12</sup> particles)
$\langle p/\text{sec} \rangle$ to target	18	18	Tp
$\langle p/10^7 \text{sec} \rangle$ to target	1.8	1.8	10 <sup>20</sup>
duty factor	90	30	%
Maximum stored in Recycler	—	4	Tp
Maximum stored in Accumulator	12	4	Tp
Maximum stored in Debuncher	12	1	Tp
Max. space charge $\Delta\nu$	$\sim 0.1$	$\sim 0.008$	
Recycler RF			
broadband	—	4	kV
2.5 MHz	—	80	kV
5.0 MHz	—	16	kV
Accumulator RF			
$h = 84$ (53 MHz)	50	—	kV
$h = 4$ (2.5 MHz)	—	$\sim 100$	kV
$h = 1$ (625 kHz)	4	—	kV
Debuncher RF			
$h = 4$ (2.35 MHz)	250	$\sim 30$	kV
$h = 1$ (588 kHz)	40	—	kV
Beam at Target:			
final bunch length	30	30	nsec, rms
final bunch intensity	$3.4 \times 10^7$	$10 \times 10^7$	
final momentum spread	8	2	10 <sup>-3</sup> , rms
transverse emittance	$< 20$	$< 20$	$\pi$ mm-mrad, norm., 95%
length of each spill	600	16	ms